(54) Title: METHOD AND APPARATUS FOR LIMITING INTERFERENCE BETWEEN SATELLITE SYSTEMS

(57) Abstract

A method and apparatus for preventing interference between a first satellite and a second satellite which share frequencies for their up or down links. A ground station receives downlink interference above an acceptable threshold from the first satellite if the first satellite and the second satellite are separated, relative to the ground station, by less than a minimum discrimination angle. Likewise, the first satellite receives unacceptable uplink interference from the ground station in that situation. To overcome the problem of interference, the second satellite is prevented from transmitting to or receiving from a forbidden area of the earth's surface. The forbidden area may either be determined as an area within which the first satellite and the second satellite are separated by less than the minimum discrimination angle, or as a band within which the first satellite is separated by less than the minimum discrimination angle from any point within an orbital band within which the second satellite is located. Communications to and from the forbidden area are either handed over to other areas outside the forbidden area for routing into the forbidden area through a ground network, or are handed over to another satellite.

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METHOD AND APPARATUS FOR LIMITING INTERFERENCE
BETWEEN SATELLITE SYSTEMS

TECHNICAL FIELD

The present invention relates generally to satellite communication systems,
5   and particularly to methods and systems for limiting signal interference
between satellite communication systems.

BACKGROUND ART

The recent proliferation of satellite communication systems has increased the
likelihood of interference between signals associated with neighboring
10   satellites. Such interference can take place, for example, when a non-
geostationary satellite comes within the field of view of a geostationary
satellite. As is well known, geostationary satellites remain fixed in equatorial
orbits over particular locations on the surface of the earth. Since
geostationary satellites ordinarily exhibit some minor variation in latitude
15   relative to the equatorial arc, there exists a narrow "geostationary band"
centered about the equatorial arc corresponding to the set of orbital locations
potentially occupied by geostationary satellites. Unlike geostationary
satellites, the orbits of non-geostationary satellites continuously vary with
respect to the earth's surface. Non-geostationary satellites typically traverse
20   low and medium altitude orbits below the geostationary band.

Signal interference between geostationary and non-geostationary
communication systems can result when non-geostationary satellites move
into the field of view of ground stations oriented toward a particular sat llite
within the geostationary band. The potential for such interference arises
25   whenever a non-geostationary satellite becomes located proximate the f eder
link path between a geostationary satellite and one of its ground stations,
hereinafter referred to as GSY ground stations. Such interference can occur
because non-geostationary satellite systems are generally allocated, on a
secondary basis, the same feeder link frequency bands primarily earmarked

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to geostationary systems. Consequently, it is incumbent upon the operators of non-geostationary systems. Consequently, it is incumbent upon the operators of non-geostationary systems to avoid disrupting communication within geostationary systems. Although it is conceivable that the feeder link band could be shared by geostationary and non-geostationary systems, the frequency separation required between the channels allocated to each system in order to ensure acceptable interference levels would make this approach unfeasible under most circumstances.

Since geostationary satellites are distributed throughout the geostati nary band above the surface of the equator, the points on the surface of the earth in approximate alignment with the geostationary band and a non-geostationary satellite form a range of "in-line" latitudes across the earth's surface. The position of this terrestrial in-line latitude range will vary with changes in the latitude of the non-geostationary satellite. Yet non-geostationary satellites may interfere with geostationary systems even when not so aligned between a geostationary satellite and a GSY ground station, since the antenna of the GSY ground station projects a radiation pattern across a finite discrimination angle relative to its beam axis. Accordingly, it has generally been necessary for non-geosynchronous satellites to cease signal transmission when in orbit above GSY ground stations in the vicinity of this in-line latitude range. This restriction on transmission range has hindered the performance of non-geostationary satellite systems coordinated in frequency with geostationary systems.

One way of minimizing interference between satellite systems would be simply to operate one system over frequency bands not already allocated to the other systems. Unfortunately, the limited frequency spectrum available for satellite communication systems renders this solution untenable. Moveover, well-established technology is available for implementing communications equipment designed to process signals over the frequency bands primarily allocated to geosynchronous systems.

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While most satellite systems have in the past used geostationary or geosynchronous satellites, the future development of systems using low and medium earth orbits is likely to increase the problem of interference, not only between geostationary and non-geostationary systems, but also between two

5   or more non-geostationary systems.

US Patent No. 5,227,802 discloses a method of controlling the amount of overlap between cells projected by different satellites, by turning off cells from one satellite when they overlap by more than a predetermined amount with cells from another satellite.

10   DISCLOSURE OF THE INVENTION

According to one aspect of the present invention, there is provided a method of reducing interference between transmissions from a first satellite and from one or more second satellites located within one or more orbital locati ns, comprising: determining a forbidden area of the surface of the earth within

15   which said first satellite and each of said orbital locations are separated by less than a predetermined minimum discrimination angle, and inhibiting transmission by the first satellite to said forbidden area.

According to another aspect of the present invention, there is provided a method of reducing interference in a link via a first satellite from

20   transmissions from one or more ground stations to one or more second satellites located within one or more orbital locations, comprising: determining a forbidden area of the surface of the earth within which said first satellite and each of said orbital locations are separated by less then a predetermined minimum discrimination angle, and inhibiting reception via the first satellite

25   from said forbidden area.

According to another aspect of the present invention, there is provided apparatus for reducing interference between transmissions from a first satellite and from one or more second satellites located within one or more

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orbital locations, comprising: means operable to determine a forbidden area
of the surface of the earth within which said first satellite and each of said
orbital locations are separated by less than a predetermined minimum
discrimination angle, and means operable to inhibit transmission by the first
5   satellite to said forbidden area.

According to another aspect of the present invention, there is provided
apparatus for reducing interference in a link via a first satellite from
transmissions from one or more ground stations to one or more second
satellites located within one or more orbital locations, comprising: means
10   operable to determine a forbidden area of the surface of the earth within
which said first satellite at said orbital locations are separated by less than a
predetermined minimum discrimination angle and means operable to inhibit
reception via the first satellite from said forbidden area.

An advantage of the present invention is that the first satellite is only
15   inhibited from transmitting to or receiving from those areas in which
unacceptable   interference   will   occur,   instead   of   inhibiting
transmission/reception whenever the beams of the first satellite and the
second satellite or satellites overlap. In this way, disruption of the servic
provided by the first satellite is reduced.

20   Communications with ground stations in the forbidden area may be handed
over to a third satellite which is able to communicate with the ground
stations without interference.

Alternatively, communications between the first satellite and ground stations
within the forbidden area may be handed over to ground stations outside the
25   forbidden area. Where the ground stations provide alternative gateways into
a ground network, communications with the ground network may thereby be
maintained.

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Communication with ground stations in the forbidden area may be inhibited by adjusting the antenna beam pattern of the first satellite, preferably by inhibiting spot beams incident on the forbidden area. This provides an advantageous method of reducing interference, since the carrier frequencies

5   and/or reference signals of the antenna beam pattern are also inhibited in the forbidden area.

The predetermined discrimination angle may correspond to a predetermined threshold of said interference, so as to ensure that a desired threshold of interference is not exceeded. The forbidden area may be determin d by

10   obtaining the present instantaneous position of each second satellite, which is complex and requires that information on the position of each second satellite is available, but minimizes the size of the forbidden area.

Alternatively, the forbidden area may be determined as the area in which the first satellite is separated by less than the minimum discrimination angle from

15   any location in an orbital band which encompasses all possible positions of the second satellite or satellites. An orbital band is easier to determine than the positions of satellites within the orbital band, although this approach enlarges the forbidden area.

The or each second satellite may be geosynchronous or geostationary, in

20   which case the position of the or each second satellite is comparatively easy to determine. In particular, the position of the geostationary orbital band is particularly easy to determine, and the majority of existing satellites are located within it.

Functions of the present invention may be controlled from the ground and

25   may be implemented to a greater or lesser extent within the satellite.

BRIEF DESCRIPTION OF THE DRAWINGS

Specific embodiments of the invention will now be described with reference

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to the accompanying drawings, in which:

Figure 1 shows a geostationary satellite and a non-geostationary satellite in orbit above the earth's surface.

Figure 2 illustratively represents the non-geostationary orbital path followed
5   by a conventionally-equipped non-geostationary satellite relative to a geostationary satellite occupying an orbital location in the geostationary band above the equator.

Figure 3 shows a non-geostationary satellite NG' equipped with a forbidden band antenna control system traversing a non-geostationary orbital trajectory
10   NGO'.

Figure 4 depicts the relationship of a non-geostationary satellite relative to a geostationary satellite and to the earth.

Figure 5 shows a block diagram of a forbidden band antenna control syst m of the present invention designed for inclusion within a non-geostationary
15   satellite.

Figure 6 is a diagram depicting various geometrical relationships between a geostationary satellite G and a non-geostationary satellite I relative to the earth.

Figure 7a shows an exact representation and an approximation of a forbidden
20   band within the field of view of a non-geostationary satellite.

Figure 7b shows a projection of a forbidden band in the field of view of a non-geostationary satellite located at a particular orbital position.

Figur 8a includes a representation on the earth's surface of the horizontal

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approximation   f the forbidden band shown in Figure 7a.

Figure 8b shows a representation of a set of forbidden bands on the surface
of the earth corresponding to various non-geostationary orbital positions.

Figure 9 shows a situation in which calls are handed over to a different
5   ground station, to avoid the forbidden band.

Figure 10 shows a situation in which calls are handed over to a different non-
geostationary satellite to avoid the forbidden band.

MODES FOR CARRYING OUT THE INVENTION
Introduction
10   Referring to Figure 1, there is shown a geostationary satellite 10 and a non-
geostationary satellite 20 in orbit above the earth's surface 30.   The
geostationary orbital trajectory of the satellite 10 passes perpendicularly
through the plane of Figure 1, while the non-geostationary satellite 20 may
be assumed

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to be in a polar orbit transverse to the ge stationary band. The geostationary satellite 10 occupies a location within the geostationary band above the equator Q, and hence remains in a fixed position relative to ground station 40. In the system shown in Figure 1 the geostationary satellite 10 provides a
5   communication link to the ground station 40. The geostationary satellite 10 communicates with the ground station 40 via antenna 60 over channels included within a feeder link band that may be simultaneously utilized by the non-geostationary satellite 20.

10   As may be appreciated by reference to Figure 1, the potential for interference between the non-geostationary satellite 20 and the geostationary satellite 10 arises when the non-geostationary satellite 20 becomes located proximate th feeder link path (FP) between the geostationary satellite 10 and the ground station 40. In accordance with the invention, signals transmitted by the
15   non-geostationary satellite 20 are prevented from interfering, beyond a predefined extent, with signal transmission between the geostationary satellit 10 and ground station 40 by modifying the antenna beam pattern B radiated by the non-geostationary satellite 20. As is described more fully below, this modification involves nulling the portion of the beam pattern incident on a
20′   "forbidden band" of latitudes (not shown to scale in Figure 1) on the surfac of the earth. The forbidden latitude range corresponds to the set of locations from which the angular separation, i.e., topocentric angle, between satellite positions within the geostationary band and the non-geostationary satellite is such that more than a minimum acceptable level of interference would exist betwe n
25   signals from the geostationary and non-geostationary satellites 10 and 20 if beam pattern B from the non-geostationary satellite 20 was not altered. The topocentric angular separation corresponding to this minimum acceptable level of interference is derived below, and will be referred to hereinafter as the minimum discrimination angle D_{min}.

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The mann r in which the present invention allows a non-g ostationary satellite to remain operational even when in view of ground stations in communication with geostationary satellites may be further appreciat d with reference to Figures 2 and 3. Figure 2 depicts a non-geostationary orbital path NGO

5   followed by a conventionally-equipped non-geostationary satellite NG relative to an orbital location in the geostationary band, above the equator Q, of a geostationary satellite G. When the satellite NG reaches orbital location A, the topocentric angular separation between the two satellites from surface location B is equal to the minimum discrimination angle. As the satellite NG traverses

10 the orbital path NGO between orbital locations A and C, there will exist points on the surface of the earth between locations B and D for which the topocentric angle between the satellites is less than the minimum discrimination angle D_{min}. This may be seen by observing that when the non-geostationary satellite NG occupies orbital positions between points E and F there exist locations between

15 points B and D on the surface of the earth from which the two satellites are in alignment, i.e., locations at which the topocentric angle is zero. It is further observed that for non-geostationary orbital locations between positions A and E, and between positions F and C, the corresponding topocentric angles at points B and D, respectively, are less than D_{min}.

20'
One way of guaranteeing that all ground stations between surface locations B and D experience less than the minimum acceptable level of interference would be to suspend transmission from the satellite NG while it is located betw en orbital positions A and C. The infeasibility of this approach, however, may be

25 demonstrated by considering the following numerical example. Assuming a typical minimum discrimination angle D_{min} of 3 degrees, a +/- 3 degree latitude variation of the geostationary satellite orbiting at a height of 35,786 km, and a non-geostationary orbit height of 1800 km, the non-geostationary satellite would need to be switched off when between latitudes approximately +/-48 degrees

30 from the equator. An interruption in communication due to this switch-off could

only be avoided if other satellites having unused feeder link capacity were available to relay signals from the non-geostationary satellite to its ground station. As described in the following section, a non-geostationary sat llite designed in accordance with the invention to selectively communicate only with

5 locations not encompassed by a "forbidden band" of latitudes allows for substantially improved coverage range.

Overview of Forbidden Band Implementation

As shown in Figure 3, a non-geostationary satellite NG' equipped with a

10 forbidden band antenna control system is seen to follow a non-geostationary orbital trajectory NGO'. In accordance with the invention, the antenna b am projected by the satellite NG' is directed only to those regions on the surface of the earth from which the topocentric angular separation between the sat llite NG' and the geostationary orbit exceeds the minimum discrimination angle

15 D_{min}. In other words, for each latitude position on the orbital trajectory NGO' there exist locations on the earth between a forbidden band of latitudes within the field of view of the satellite NG' from which the topocentric angle is less than D_{min}. The location of this forbidden band of latitudes will shift as the satellite NG' traverses the orbital trajectory NGO'. In keeping with the

20' invention, the antenna beam projected by the satellite NG' is shaped so as to only transmit signals to, and receive signals from, locations on the surface of the earth not covered by the forbidden band.

As shown in Figure 3, the forbidden band of latitudes corresponding to the

25 indicated orientation of the non-geostationary satellite NG' relative to a geostationary satellite G' extends from latitude L1 to latitude L2 about the equator Q. The forbidden band is positioned such that on the latitudes L1 and L2 the topocentric angle between the satellites is equivalent to th minimum discrimination angle D_{min}. It follows that the topocentric angle

30 associated with locations within the forbidden band is less than D_{min}, while the

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topocentric angular separation between th satellites corresponding to locati ns outside of the forbidden band is larger than D_{min}. In a preferred embodiment of the invention the antenna beam pattern from the satellite NG' is continuously modified so as not to illuminate the forbidden band corresponding to th

5   instantaneous latitude of the satellite NG'. This may be effected by, for example, selectively energizing a cluster of spot beams projected by th antenna of the satellite NG' in accordance with a switching algorithm. The switching algorithm will typically be responsive to latitude information receiv d from either the orbit control system of the satellite or a ground station. In this

10   regard a more detailed description of a forbidden band antenna control syst m is set forth in a following section.

Determination of the Minimum Discrimination Angle D_{min}

Interference calculations are performed by separately considering interferenc

15   between non-geostationary and geostationary downlink (i.e., satellite to earth) and uplink (i.e., earth to satellite) frequency bands. That is, any interference between uplink and downlink bands is assumed to be of nominal magnitude relative to interference between bands of like type.

20.   In a particular embodiment of the invention the value of the minimum discrimination angle, and hence the extent of the forbidden band, depends in part upon the signal to noise ratio required for communications carried by the feeder link between the geostationary satellite 10 and ground station 40. Determination of the impact of signal transmissions from the non-geostationary

25   satellite 20 upon this signal to noise ratio will generally require knowledge of the frequency and modulation characteristics of the feeder link, as well as of specific aspects of the communications hardware incorporated within the geostationary and non-geostationary satellites 10 and 20 and within the ground station 40. In this regard it will generally be necessary to be aware of the

30   shape, or type, of the antenna beam B nominally projected by the satellite 20,

the gain of the antennas associated with the earth station 40 and geostationary satellite 10, and the frequency (e.g., C-Band, Ku-Band) and carrier characteristics (e.g., CDMA) of the feeder link.

5   Derivation of the Topocentric Angle η:

Figure 4 is a diagram depicting the geometric relationship of a non-geostationary satellite S' relative to a geostationary satellite S and to the earth. The angular separation between the geostationary and non-geostationary satellites S and S' as seen from the center of the earth is
10   denoted by α, while the separation between these satellites as seen from the location of a ground station on the surface of the earth is identified as the topocentric angle η. Given a particular value of the angle α between th two satellites, the corresponding topocentric angle η will vary in accordance with the location of the ground station on the surface of the earth. It is assumed that
15   the worst case interference situations arise when the topocentric angle is at a minimum for a given geocentric angle α; that is, interference will be most pronounced when the angular separation between the satellites is at a minimum when viewed from a ground station. Although the distances betw en the ground station and the satellites vary as a function of the latitude of th
20   ground station, such variation is believed to have a negligible effect on interference levels relative to that arising as a consequence of changes in the topocentric angle η.

Referring to Figure 4, it may be seen that there exist geocentric angles for
25   which the minimum topocentric angle, i.e., η_{min}, is larger than zero. This corresponds to the situation in which the satellites are not aligned from any location on the surface of the earth. Whether or not the minimum topocentric angle η_{min} is nonzero will depend upon the orbit heights h and h' of the geostationary and non-geostationary satellites relative to the surface of the
30   earth. In particular, for orbit heights h and h' resulting in a geocentric angle α

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less than a threshold angle α_{min} there will exist ground station locations represented by the vector E for which th minimum topocentric angle η_{min} is zero. Conversely, for satellite orbit configurations in which $\alpha > \alpha_{min}$ there exist ground station locations for which the associated topocentric angle η_{min} is not

5   zero. The angle α_{min} may be derived using plane geometry, and is expressed below as:

$$\alpha_{min} = \arccos\left(\frac{Ro}{Ro+h}\right) - \arccos\left(\frac{Ro}{Ro+h'}\right) \tag{1}$$

where Ro is the earth's radius, and h and h' are the respective orbit heights of the geostationary and non-geostationary satellites S and S' (h>h'). Again, instances in which the geocentric angle is superior to the limit value of equation

10   (1) correspond to situations in which there are no ground station locations aligned with the two satellites, i.e., $\eta_{min} > 0$.

In what follows it is endeavored to determine an expression relating the location of a ground station to the topocentric angle η between the satellites S and S'

15   associated therewith. It is noted that the following calculations are referenc d to the non-geostationary satellite S', as is indicated by the OXYZ coordinate system used in Figure 4.

If Ro denotes the earth radius, and as previously mentioned h and h' the orbit

20   heights of geosynchronous satellite S and non-geosynchronous satellite S', respectively, wherein θ and φ are the spherical coordinates of ground station location E in the OXYZ coordinate system, one has:

$$E = \begin{pmatrix} Ro\ \sin\theta\ \cos\varphi \\ Ro\ \sin\theta\ \sin\varphi \\ Ro\ \cos\theta \end{pmatrix} \quad S = \begin{pmatrix} -(Ro+h)\ \sin\alpha \\ 0 \\ (Ro+h)\ \cos\alpha \end{pmatrix} \quad S' = \begin{pmatrix} 0 \\ 0 \\ Ro+h' \end{pmatrix} \tag{2}$$

Letting r and r' denote the ranges from ground station location E to the satellites S and S', respectively, useful vectors are defined by:

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$$r\vec{u} = ES \qquad r'\vec{u}' = ES' \tag{3}$$

so that the cosin of the topocentric angle is:

$$\cos\eta = \vec{u}.\vec{u}' \tag{4}$$

If one permits ground station location E to "move" on the surface of the earth while fixing the positions of satellites S and S', the opposite of the differential

5   of E can be written:

$$- dE = dr\vec{u} + r d\vec{u} = dr'\vec{u}' + r' d\vec{u}' \tag{5}$$

The calculation of the scalar product of this equation with the two unit vectors leads to:

$$\begin{cases} \vec{u}.d\vec{u}' = \dfrac{dr - dr'\cos\eta}{r'} \\[2mm] \vec{u}'.d\vec{u} = \dfrac{dr' - dr\cos\eta}{r} \end{cases} \tag{6}$$

The differential of the cosine of the topocentric angle is then:

$$d(\cos\eta) = \frac{dr - dr'\cos\eta}{r'} + \frac{dr' - dr\cos\eta}{r} \tag{7}$$

10

If θ is fixed, r' does not vary, so that one has:

$$\frac{\partial(\cos\eta)}{\partial\varphi} = \frac{1}{r}\frac{\partial r}{\partial\varphi}\left(\frac{r}{r'} - \cos\eta\right) \tag{8}$$

The term in brackets is positive, so that the cosine of the topocentric angle follows the variations of r and thus the variations of the square of r, which is equal to:

$$r^2 = Ro^2 + (Ro + h)^2 - 2Ro(Ro + h)(\cos\theta\cos\alpha - \sin\theta\sin\alpha\cos\varphi) \quad (9)$$

Hence, when only φ varies, the cosine of the topocentric angle follows th variations of the cosine of φ and therefore the topocentric angle, when θ is fixed, is minimum for $\varphi=0$.

5   In the rest of this section the geocentric angle is assumed to be sufficiently low that there exist ground station positions corresponding to $\varphi=0$ in the field of view of satellite S. This condition can be written:

$$\alpha \leq \arccos\left(\frac{Ro}{Ro + h}\right) \quad (10)$$

It should be noted that this condition is not very restrictive since the limit valu ,
10   for a geostationary satellite S, is 81.3 degrees.   The following notations are adopted for the rest of the section:

$$\begin{cases} \rho = \dfrac{Ro + h}{Ro} & \rho' = \dfrac{Ro + h'}{ro} \\[2mm] \beta = \arccos\left(\dfrac{1}{\rho}\right) & \beta' = \arccos\left(\dfrac{1}{\rho'}\right) \end{cases} \quad (11)$$

With these notations, the conditions on α can be written:

$$\beta - \beta' \leq \alpha \leq \beta \quad (12)$$

The fact that the ground station location represented by the vector E must be in the field of view of both satellites may be expressed using equation (12) as:

$$\theta \leq \beta - \alpha \quad (13)$$

15   Since the topocentric angle η is the difference between the elevation of S' and the elevation of S as viewed from ground station location E, it is possible to represent the angle η as follows:

$$\eta = \arctan\left(\frac{\cos\theta - \frac{1}{\rho'}}{\sin\theta}\right) - \arctan\left(\frac{\cos(\theta + \alpha) - \frac{1}{\rho}}{\sin(\theta + \alpha)}\right) \qquad (14)$$

Thus, the topocentric angle η decreases as the angle θ increases.

Forbidden Band Antenna Control System

5   Referring to Figure 5, there is shown a block diagram of a forbidden band antenna control system 100 of the present invention designed to be included within, for instance, the non-geostationary satellite NG' depicted in Figure 3. Operation of the control system 100 is coordinated by a central processing unit (CPU) 102, such as a microprocessor or the like, on the basis of instructi ns

10   received from a forbidden-band antenna control program 104 stored within an on-board memory unit 108. The memory unit 108 further includes general purpose memory 112 and a forbidden-band look-up table 116.

    The look-up table 116 contains information pertaining to the position and shape

15   of the forbidden band of locations on the surface of the earth. While in particular embodiments the forbidden band may be approximated by a strip of surface locations included between a pair of latitude boundaries, more accurate representations of the forbidden band include latitude boundaries exhibiting a longitudinal dependence. When the former approximation is employed the

20   look-up table 116 will include pairs of forbidden band latitude boundaries L1 and L2 (Figure 3) indexed as a function of the latitude of the non-geostationary satellite NG'. It is anticipated that the look-up table would include boundaries of the forbidden latitude corresponding to a set of uniformly separated latitudes. An interpolation scheme could then be used to determine forbidden band

25   boundaries corresponding to latitudes not included within the look-up table.

In order to approximate the forbidden band using latitude boundari s independent of longitude, the entries within the look-up table 116 could be derived in a simplified manner, for example, by using the expression for topocentric angle given by equation (14) above. In an initial step using this approach the minimum discrimination angle D_{min} is determined as describ d in the preceding section. Following determination of D_{min}, computation of the topocentric angles corresponding to a selected set of latitudes on the surface of the earth is generated for each satellite latitude index stored within the look-up table 116. This step may be performed by, for example, substituting into equation (14) a trial set of latitudes spanning a range believed to encompass the forbidden latitude band corresponding to the associated satellite latitude index. The topocentric angle corresponding to each latitude within the trial set is then compared with D_{min} in order to determine the latitude boundaries L1 and L2 of the forbidden band. That is, there will exist a pair of latitudes L1 and L2 within the trial set such that for all forbidden latitudes therebetween the associated topocentric angle will be less than D_{min}. This description of a simplified technique for determining the boundaries of the forbidden band is included at this juncture in order to enhance understanding of the control system 100. Accordingly, a more complete discussion of a method for determining the limits of the forbidden band is detailed in a subsequent section.

Referring to Figure 5, the antenna control system 100 also includes a position acquisition subsystem 120 for supplying to the CPU 102 information relating to the orbital location of the non-geostationary satellite. The forbidden band antenna control program 104 uses the orbit latitude provided by the subsystem 120 to retrieve the boundaries of the forbidden band from the look-up table 116. The CPU 102 then relays the retrieved forbidden band boundaries to an antenna control subsystem 124. The control subsystem 124 operates in a conventional manner to configure an antenna beam-forming network 128 used

to drive the antenna 132 of the non-geostationary satellite. The subsystem 124 controls th shape of the beam pattern projected by the antenna by determining which of the feed elements within a feed array 136 are to be energized by the beam-forming network 128. Electromagnetic energy is conventionally coupled

5   from the beam forming network 128 to the feed array 136 by waveguide 140, and is then directed by the feed 136 to a doubly-curved shaped reflector 144. Although Figure 5 depicts a particular system for projecting a forbidden-band beam pattern, other means within the scope of the invention may be used to perform this function.

10

For example, in an alternate embodiment of the antenna control system th look-up table includes information relating to longitudinal variation in th positions of the forbidden band boundaries. Such more precise forbidden band representations could each be stored, for example, as a two-dimensional matrix

15   associated with a particular orbit latitude of the non-geostationary satellit . A set of mathematical expressions from which these two-dimensional forbidden band representations could be derived is set forth below. The geometric parameters included within the following expressions are defined within the diagram of Figure 6, in which are shown various geometrical relationships

20 ′   between a geostationary (GSO) satellite G and non-geostationary (non-GSO) satellite I relative to the earth.

In another implementation of the antenna control system the look-up table will include data corresponding to amplitude and phase coefficients used in

25   controlling individual elements within the antenna feed array. Such control data will generally be transmitted from a ground station and stored within the look-up table prior to initiation of satellite operation. Since the orbit of non-geostationary satellites is periodic, it is not required to generate a separate set of control data based on recurring sets of geometrical satellite position

30   parameters. Although this approach may require a larger memory than

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implementations involving on-board generation of antenna control signals, it is simpler with regard to processing requirements and the like. Moreover, in this approach control data corresponding to repr sentations of the forbidden band exhibiting longitudinal variation could be stored as easily as those in

5   which the shape of the forbidden band is specified simply by a pair of latitudes.

In another implementation, the look-up table includes data corresponding to said amplitude and phase coefficients as a function of time, and the non-geostationary satellite has an accurate clock which can be adjusted or reset

10   by signals from the ground station. In this way, no direct position information need be stored.

While the antenna control system 100 of Figure 5 is designed for incorporation in the non-GSO satellite, in an alternative embodiment elements of the control system 100 are incorporated in a ground-level control station.

15   The control station includes the position acquisition subsystem 120, the CPU 102 and the memory unit 108, and information on the forbidden band boundaries is transmitted to the antenna control subsystem 124, so that the control station inhibits communication with the forbidden band.

Geometrical Context of Forbidden Band Calculations

20   In what follows it is assumed that the position of the non-GSO satellite is fixed at a given latitude, such that all calculations correspond to a given instant in the non-GSO satellite orbital period. This allows longitude to be determined relative to the non-GSO satellite. The GSO satellite considered can have any longitude and a latitude between -3 and +3 degrees, a range

25   corresponding to the typical latitude drift of GSO satellites. In all of the following calculations the variable of interest corresponds to the location of the ground station M on the surface of the earth.

The following notations will be used hereinafter:

O, c nter of the arth;

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Ro, radius of the earth;

I, the non-GSO satellite positioned at latitude I and orbit height h';

G, the GSO satellite positions at longitude L, latitude ΔI and orbit height h wherein longitude is measured relative to the non-GSO satellite;

5   lo, the point of latitude 0 and relative longitude 0 at the same h ight as I; and

M, the instantaneous location of the ground station on the surface of the earth.

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A first reference frame in Figure 6 defined relative to the position of the non-GSO satellite may be characterized as follows:

Iz is a vector directed from the non-GSO satellite to the center of th earth;

5   Iy is a vector in the longitude plane containing I, is direct d perpendicular to Iz, and points in the north direction; and

Ix is oriented such that Ixyz is orthonormal.

A second frame of reference is denoted as IoXYZ, and is similar to the
10   reference frame Ixyz but uses Io rather than I as an origin. The referenc frame Ixyz may be obtained by rotating the reference frame IoXYZ through an angle I with respect to the axis OX. The notations used within the second reference frame of Figure 6 are:

$$
\begin{cases}
OM = Ro = a \\
OI = Ro + h' = b \\
OG = Ro + h = c \\
\rho = \dfrac{b}{c} \\
GI = d \\
\eta = I\hat{M}G = topocentric\ angle
\end{cases}
\tag{15}
$$

15   The spherical coordinates of M in Ixyz are (r, θ, φ) so that its cartesian coordinates in Ixyz are (r sinθ cosφ, r sinθ sinφ, r cosθ). A pair of directions of interest are given by the following unit vectors:

$$
\begin{cases}
u = \dfrac{1}{GI}.GI \\
v = \dfrac{1}{IM}.IM
\end{cases}
\tag{16}
$$

Determination of Forbidden Directions of Transmission from the non-GSO Satellite

In a preferred approach the forbidden transmission directions from th non-GSO satellite are calculated with respect to a set of orbit locations within
5   the geostationary band, i.e., potential positions of the GSO satellite. The forbidden directions derived with respect to each GSO satellite position may b envisioned as forming a beam, originating at the non-GSO satellite, the edges of which illuminate points on the earth's surface from which the topocentric angles between the non-GSO satellite and the associated GSO satellite are
10   equal to the minimum discrimination angle D_{min}. The following section describes a method for determining the shape of the forbidden beam in terms of a set of unit vectors $\overrightarrow{v}$, wherein each value of $\overrightarrow{v}$ specifies a linear path between the non-GSO satellite and a location on the surface of the earth. In this way the contour of the forbidden band of locations on the surface of the
15   earth may be determined with knowledge of the shape of the forbidden beam.

Referring to Figure 6, the coordinates of the satellite G may be expressed in terms of the non-GSO satellite reference Ixyz as follows:

$$\hat{OG}_{(xyz)} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos I & \sin I \\ 0 & -\sin I & \cos I \end{pmatrix} \begin{pmatrix} -c\sin I\cos\Delta I \\ c\sin\Delta I \\ -c\cos L\cos\Delta I \end{pmatrix} = \begin{pmatrix} -c\sin L\cos\Delta I \\ c\sin\Delta I\cos I - c\cos L\cos\Delta I\sin I \\ -c\sin\Delta I\sin I - c\cos L\cos\Delta I\cos I \end{pmatrix} \quad (17)$$

so that:

$$\frac{1}{c}\vec{Gl}_{(xyz)} = \begin{pmatrix} \sin L\cos\Delta I \\ \cos L\cos\Delta I\sin I - \sin\Delta I\cos I \\ \cos L\cos\Delta I\cos I + \sin\Delta I\sin I - \rho \end{pmatrix} \quad (18)$$

20   By calculating the scalar square of equation (18), one obtains:

$$d = c\sqrt{1 + \rho^2 - 2\rho(\cos L\cos I\cos\Delta I + \sin I\sin\Delta I)} \quad (19)$$

The range r between a ground station location and the non-GSO satellite may be expressed as:

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$$r = b\cos\theta - \sqrt{a^2 - b^2\sin^2\theta} \qquad (20)$$

Furthermore,

$$\cos\eta = \frac{1}{MI.MG}.\overline{MI}.\overline{MG} = \frac{\overline{MI}^2 + \overline{MI}.\overline{IG}}{MI.\sqrt{(\overline{MI} + \overline{IG})^2}} = \frac{r + d.\vec{u}.\vec{v}}{\sqrt{d^2 + r^2 + 2rd.\vec{u}.\vec{v}}} \qquad (21)$$

leads to:

$$\vec{u}.\vec{v} = -\frac{r}{d}\sin^2\eta + \cos\eta\sqrt{1 - \frac{r^2\sin^2\eta}{d^2}} \qquad (22)$$

5

Combining equations (19), (20) and (22), one thus has $\vec{u}.\vec{v}$ in function of θ. The two unit vectors given by equation (16) may also be represented in the xyz reference as follows:

$$\left| \begin{array}{l} \vec{u}_{xyz} = \dfrac{1}{\sqrt{1 + \rho^2 - 2\rho(\cos L\cos l\cos\Delta l + \sin l\sin\Delta l)}} \cdot \begin{pmatrix} \sin L\cos\Delta L \\ \cos L\sin l\cos\Delta l - \cos l\sin\Delta L \\ \cos L\cos l\cos\Delta l - \sin l\sin\Delta L - \rho \end{pmatrix} \\[16pt] \vec{v}_{xyz} = \begin{pmatrix} \sin\theta\cos\varphi \\ \sin\theta\sin\varphi \\ \cos\theta \end{pmatrix} \end{array} \right. \qquad (23)$$

10   so that:

$$\vec{u}.\vec{v} = \frac{\left(\begin{array}{l}\sin L\cos\Delta l\sin\theta\cos\varphi \\ + (\cos L\sin l\cos\Delta l - \cos l\sin\Delta l)\sin\theta\sin\varphi \\ + (\cos L\cos l\cos\Delta l + \sin l\sin\Delta l - \rho)\cos\theta)\end{array}\right)}{\sqrt{1 + \rho^2 - 2\rho(\cos L\cos l\cos\Delta l + \sin l\sin\Delta l)}} \qquad (24)$$

Combined with the other expression of $\vec{u}.\vec{v}$ given in equation (22), equation (24) leads to a relation between θ and φ, which can be written:

$$A(\theta)\cos\varphi + B(\theta)\sin\varphi = C(\theta) \qquad (25)$$

This results in 0, 1 or 2 values of φ for a given value of θ. For a solution (θ,φ) of the equation, the corresponding unit vector $\vec{v}$ corresponds to the direction of a ray on the periphery of the "forbidden beam", i.e., the beam defined by the values of l, L, Δl and η. The calculation of φ values corresponding to a sufficient number of θ values thus yields an approximation of the contour of th forbidden beam under consideration. Superposition of a sufficient number of forbidden beams, with each forbidden beam corresponding to a particular GSO satellite location, enables determination of the forbidden band of locations on the surface of the earth associated with the location of the non-GSO satellite. In a particular implementation the GSO satellite locations considered are at specified values of allowed GSO satellite drift latitude (e.g., +3 and -3 degrees). At each drift latitude calculations are performed from a plurality of longitud s relative to the longitude of the non-GSO satellite.

Representation of the Forbidden Band in the Non-GSO Satellite Reference
Referring to Figure 6, each direction from the non-GSO satellite l is represented by the projection in plane lxy of the corresponding unit vector. Each forbidden direction, defined by a value of θ and a value of φ, is thus represented in a plane by a point of cartesian coordinates ($x = \sin\theta \cos\varphi$, $y = \sin\theta \sin\varphi$). In this representation format the field of view of the non-GSO satellite is circular.

It is noted that this representation format differs from a satellite referenc in which azimuth and elevation are specified. In these two representations the directions from the satellite are related by:

$$\begin{cases} x = \cos El \sin Az \\ y = \sin El \end{cases} \qquad (26)$$

and are thus coincident when small angles are involved. In azimuth/elevation

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repres ntation, the field of view of the satellite will not be circular unless both the azimuth and the elevation angles are small.

An exact representation of the forbidden band requires consideration of the
5   forbidden beams corresponding to all positions within the geostationary band within view of the non-GSO satellite under consideration. Nonetheless, in particular implementations it may be sufficient to approximate this exact representation by a horizontal latitude band encompassing all points within the exact representation.   This approximation may be defined in terms of two
10   values of elevation within the field of view of the non-GSO satellite. Moreover, this horizontal approximation of the forbidden band allows a straightforward realization of the antenna 132 (Figure 5) of the non-GSO satellite as a conventional linear feed array.

15   Referring to Figure 7a, an exact representation and an approximation of a forbidden band are shown within the field of view (FOV) of a non-geostationary satellite. In particular, the exact forbidden band is shown as the cross-hatched region between the dashed lines while the horizontal approximation is defined by the elevations E1 and E2. The particular example of Figure 7a corresponds
20   to the situation in which the non-GSO satellite is in orbit at an altitude of 1800 km at a latitude of 25 degrees, and in which the minimum discrimination angle required for acceptable interference is 7 degrees. This results in a forbidden band approximation in which the elevations E1 and E2 are at 10.1 degrees and 41.8 degrees, respectively, relative to the center C1 of the non-GSO field of
25   view.

An additional example of a projection of the forbidden band within the field of view of a non-GSO satellite at an altitude of 1800 km at a latitude of 10 degress is provided by Figure 7b. Specifically, forbidden bands are shown for
30   minimum discrimination angles of 3 degrees (solid line), 5 degrees (dashed

line), and 7 degrees (dott d line). In the representation of Figure 3 the forbidd n bands correspond to orthographic (sine) projections mapped according to the function sin(θ), where θ denotes latitude.

5   **Representation of Forbidden Band on Surface of Earth**

In this section the forbidden band within the non-GSO satellite reference depicted in Figure 7a will be transformed to a corresponding forbidden band on the surface of the earth. The transformation entails calculation of the longitude L_M and latitude l_M (with respect to the non-GSO satellite position) of the point

10   M on the earth's surface corresponding to a given direction from the non-GSO satellite. This calculation requires finding an xyz coordinate representation of the vector $\overrightarrow{OM}$ based on the following expression:

$$\begin{cases} - a\cos l_M \sin L_M = r\sin\theta\cos\varphi \\ \quad a\sin l_M = r\sin\theta\sin\varphi\cos l - r\sin l\cos\theta + b\sin l \\ -a\cos l_M \cos L_M = r\sin\theta\sin\varphi\sin l + r\cos\theta\cos l - b\cos l \end{cases} \quad (27)$$

The values of l_M and L_M are then simply derived as functions of θ and φ. This transformation from (θ,φ) to (L_M,l_M) allows the intersection with the earth's

15   surface of any ray from the non-GSO satellite to be represented in terms of longitude and latitude upon an earth map. The transformation is initiated by considering (i) the representation of the field of view of the non-GSO satellit :

$$\theta = \arcsin\left(\frac{a}{b}\right) \quad (28)$$

and, (ii) the two values of elevation (El) within the non-GSO reference frame associated with the boundaries of the horizontal approximation of the forbidden

20   band. The following expression holds at each boundary elevation El:

$$\sin\theta\sin\varphi = \sin El \quad (29)$$

Referring to Figure 8a, there is shown a representation on the earth's surface

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of the horizontal forbidden band of Figure 7a. Specifically, the field of view of the non-GSO satellite is denoted in Figure 8a by the solid line FOV', while the limits of the approximation of the forbidden band are indicated by the dashed line E1' and E2'. It is noted that the horizontal limited E1 and E2 of the forbidden band within the non-GSO satellite reference are transformed to the curved segments E1' and E2' on the earth's surface.

As an additional example, Figure 8b shows projections upon the earth's surface of a set of forbidden bands (solid lines) together with the projections of the associated fields of view (dashed lines). The projections correspond to a plurality of latitude positions of a non-GSO satellite in orbit at an altitude of 1800 km, and assume a minimum discrimination angle of 7 degrees. The relative longitudinal positions of the forbidden bands were varied in order to minimize mutual superposition.

Alternative Implementations

Referring again to Figure 5, in other embodiments of the antenna control system 100 the boundaries of the forbidden band could be determined in real-time rather than using a look-up table 116. For example, latitude and longitude information from the position acquisition subsystem 120 (Figur 5) could be used by a microprocessor or the like on-board the non-geostationary satellite to determine the shape of the forbidden band in accordance with the analytical expressions set forth in the above equations. In another implementation such real-time calculations would be performed at a ground station and transmitted to the non-geostationary satellite. In each of these implementations the control system 100 would then operate as described above to project an antenna beam only to those regions outside of the forbidden band.

The calculation of the forbidden beam is used above to derive the contour of the forbidden band. However, in an alternative embodiment in which the precise position of the GSO satellite is known, the instantaneous forbidden

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beam is used to define a forbidden area with which the non-GSO satellite does not communicate, the forbidden area being smaller than the forbidden band.

Furthermore, the above equations for the forbidden beam are not specific to
5   a combination of a GSO and a non-GSO satellite, but may be applied to any two satellites, so that a forbidden beam may be calculated in any situation involving interference between two satellites and transmission from or reception by one of the satellites may be inhibited in the forbidden beam.

HANDOVER

10   In each of the above methods, the non-geostationary satellite 20 is prevented from communicating with any ground station within the forbidden band or beam. However, an object of using non-geostationary satellites is to provide global or near global coverage. Therefore, calls routed between the non-geostationary satellite 20 and ground stations within the forbidden band or
15   beam should not be cut off, but should be handed over in a way that avoids the forbidden band or beam.

Figure 9 shows a situation in which first and second ground stations 50 and 52, which are designed for communication with the non-geostationary satellite 20, are both linked via a ground network 54 to a PSTN 56. Calls are
20   routed between a third ground station 58 and the PSTN 56 via the non-geostationary satellite 20 and the first ground station 50. However, as the non-geostationary satellite 20 moves with respect to the earth's surface, the first ground station 50 falls within a forbidden band or beam with respect to the geostationary satellite 10, so that communication with the first ground
25   station 50 is not possible without interference with the feeder-link path FP between the geostationary satellite 10 and the ground station 40.

In this case, calls are handed over from the first ground station 50 to the second ground station 52, which is not located within the forbidden band or

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beam, so that the link between the third ground station 58 and the PSTN 56 is maintained. The handover is preferably controlled by determining which calls are routed through a spot-beam which covers the first ground station 50 and re-routing the calls through a spot-beam which covers the second ground
5   station 52, and may either be controlled by the third earth station 58 or the non-geostationary satellite 50.

It is to be noted that the extent of the forbidden band or beam depends on the value of Dmin, which depends partly on the directional properties of the antennas associated with the ground station 40, the non-geostationary
10   satellite 20 and the geostationary satellite 10. The first and second ground stations 50 and 52 may be equipped with directional or omnidirectional antennas without affecting the extent of the forbidden band or beam.

An alternative situation will now be described with reference to Figure 10, in which a communication link is set up between the third ground station 58
15   and a mobile ground station 59. In this case, it is not acceptable to handover calls to an alternative ground station as in Figure 9, because the mobile ground station 59 is not connected to a ground network which would allow it to receive the calls after they are handed over.

Instead, when the mobile ground station 59 falls within a forbidden band or
20   beam with respect to the geostationary satellite 10 and the non-geostationary satellite 20, calls are handed over from the non-geostationary satellite 20 to a further non-geostationary satellite 25 for which the mobile station 59 does not fall within a forbidden band. Preferably, the handover is controlled by the third ground station 58.

25   While the present invention has been described with reference to a few specific embodiments, the description is illustrative of the invention and is not to be construed as limiting the invention. Various modifications may occur to those skilled in the art without departing from the scope of the invention as defined by the appended claims.

30

CLAIMS:

1.   A method of limiting interference between transmissions from a first satellite and from one or more second satellites located within one or more orbital locations, comprising:

5   determining whether a forbidden area of the surface of the earth, within which said first satellite and each of said orbital locations are separated by less than a predetermined minimum discrimination angle, is located within the field for view of the first satellite, and

        allowing transmission by the first satellite only to areas outside said

10   forbidden area.

2.   A method as claimed in claim 1, further comprising allowing transmission to said forbidden area by a third satellite separated from each of said orbital locations by greater than said predetermined minimum discrimination angle within said forbidden area.

15   3.   A method as claimed in claim 1, further comprising handing over transmission by said first satellite from a first ground station within said forbidden area to a second ground station outside said forbidden area.

4.   A method of limiting interference in a link via a first satellite from transmissions from one or more ground stations to one or more second

20   satellites located within one or more orbital locations, comprising:

        determining whether a forbidden area of the surface of the earth, within which said first satellite and each of said orbital locations are separated by less then a predetermined minimum discrimination angle is located within the field of view of the first satellite, and

25   allowing reception via the first satellite only from areas outside said forbidden area.

5.   A method as claimed in claim 4, further comprising allowing reception from said forbidden area by a third satellite separated from each of said orbital

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locations by greater than said predetermined minimum discrimination angle within said forbidden area.

6. A method as claimed in claim 4, further comprising handing over reception by said first satellite from a first ground station within said forbidden area to a second ground station outside said forbidden area.

7. A method as claimed in any preceding claim, further comprising adjusting the antenna beam pattern of the first satellite so as not to cover said forbidden area.

8. A method as claimed in claim 7, wherein the antenna beam pattern is adjusted by inhibiting spot beams incident on said forbidden area.

9. A method as claimed in any preceding claim, wherein said predetermined discrimination angle corresponds to a predetermined threshold of said interference.

10. A method as claimed in any preceding claim, wherein said one or more locations comprises the instantaneous position of the one or more second satellites.

11. A method as claimed in any one of claims 1 to 9, wherein said one or more locations comprises an orbital band within which said one or more second satellites are confined.

12. A method as claimed in claim 10 or 11, wherein said one or more second satellites are geosynchronous.

13. A method as claimed in claim 12, wherein said one or more second satellites are geostationary.

14.   A method as claimed in claim 13, wherein the forbidden area determining step includes the step of determining a range of latitudes within which said separation is less than said predetermined discrimination angl .

15.   A method as claimed in any preceding claim, wherein said method steps
5   are executed by a ground station.

16.   Apparatus for limiting interference between transmissions from a first satellite and from one or more second satellites located within one or more orbital locations, comprising:
        means operable to determine whether a forbidden area of the surfac of
10   the earth, within which said first satellite and each of said orbital locations ar separated by less than a predetermined minimum discrimination angle, is located within the field of view of the first satellite, and
        means operable to allow transmission by the first satellite only to ar as outside said forbidden area.

15   17.   Apparatus as claimed in claim 16, further comprising means operabl to allow transmission to said forbidden area by a third satellite separated from each of said orbital locations by greater than said predetermined minimum discrimination angle within said forbidden area.

18.   Apparatus as claimed in claim 16, further comprising means operable to
20   hand over transmissions by said first satellite from a first ground station within said forbidden area to a second ground station outside said forbidden area.

19.   Apparatus for limiting interference in a link via a first satellite from transmissions from one or more ground stations to one or more s cond satellites located within one or more orbital locations, comprising:
25   means operable to determine whether a forbidden area of the surface of the earth, within which said first satellite and said orbital locations ar separated by less than a predetermined minimum discrimination angl , is

located within the field of view of the first satellite, and means operabl to allow reception via the first satellite only from areas outside said forbidden area.

20.   Apparatus as claimed in claim 19, further comprising:

5   means operable to allow reception from said forbidden area by a third satellite separated from each of said orbital locations by greater than said predetermined minimum discrimination angle within said forbidden area.

21.   Apparatus as claimed in claim 19, further comprising:

        means operable to hand over reception by said first satellite from a first

10   ground station within said forbidden area to a second ground station outside said forbidden area.

22.   Apparatus as claimed in any one of claims 6 to 21, further comprising means arranged to adjust the antenna beam pattern of the first satellite so as not to cover said forbidden area.

15   23.   Apparatus as claimed in claim 22, wherein the adjusting means is arranged to adjust the antenna beam pattern by inhibiting spot beams incident on said forbidden area.

24.   Apparatus as claimed in any one of claims 16 to 23, wherein said predetermined discrimination angle corresponds to a predetermined threshold

20   of said interference.

25.   Apparatus as claimed in any one of claims 16 to 24, wherein said one or more locations comprises the instantaneous position of the one or more second satellites.

26.   Apparatus as claimed in any one of claims 16 to 24, wherein said one

25   or more locations comprises an orbital band within which said one or more

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second satellites are confined.

27. Apparatus as claimed in claim 25 or 26, wherein said one or more second satellites are geosynchronous.

28. Apparatus as claimed in claim 27, wherein said one or more second

5   satellites are geostationary.

29. Apparatus as claimed in claim 28, wherein the forbidden area determining means includes means operable to determine a range of latitudes within which said separation is less than said predetermined discrimination angle.

10   30. A ground station including apparatus as claimed in any one of claims 16 to 29.

31. A satellite including apparatus as claimed in any one of claims 16, 18, 19, 21 or any one of claims 22 to 29 when dependent thereon, for use as said first satellite.
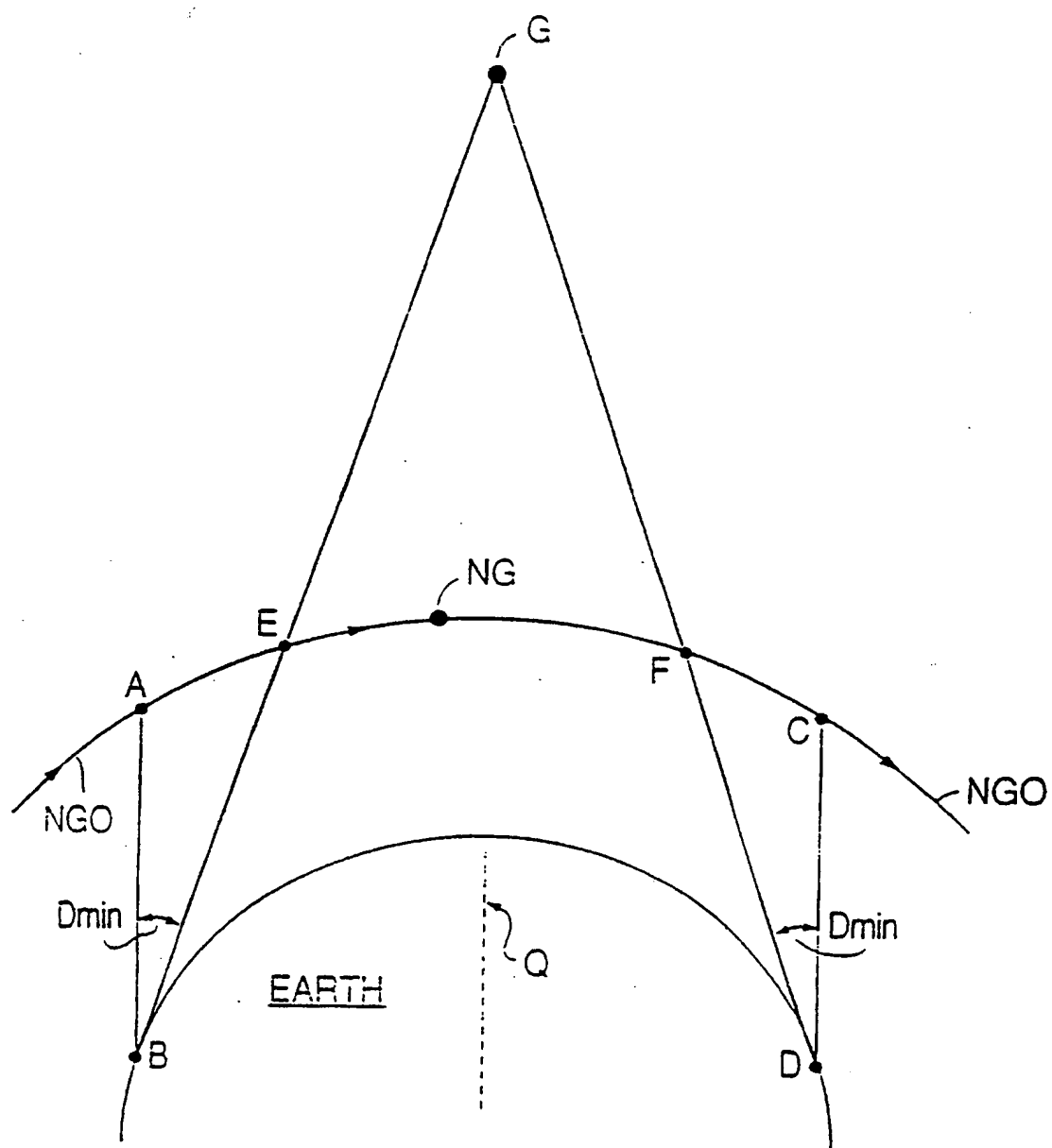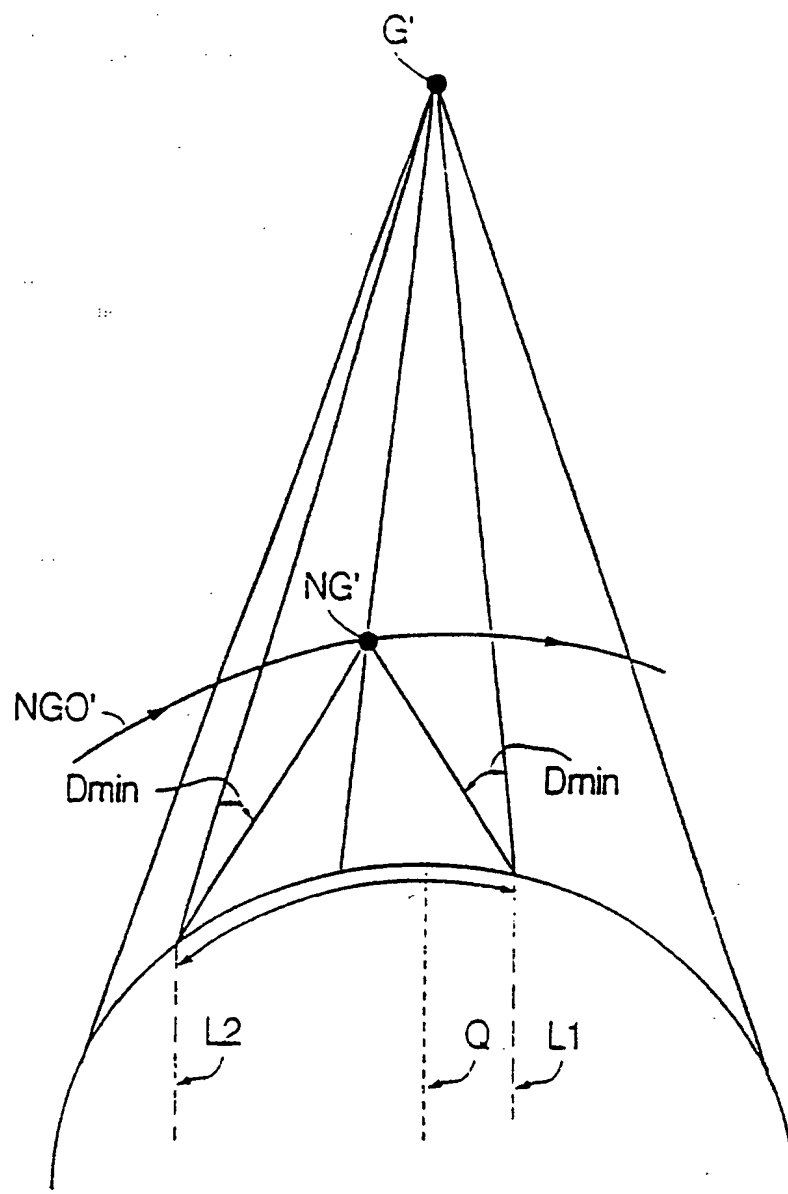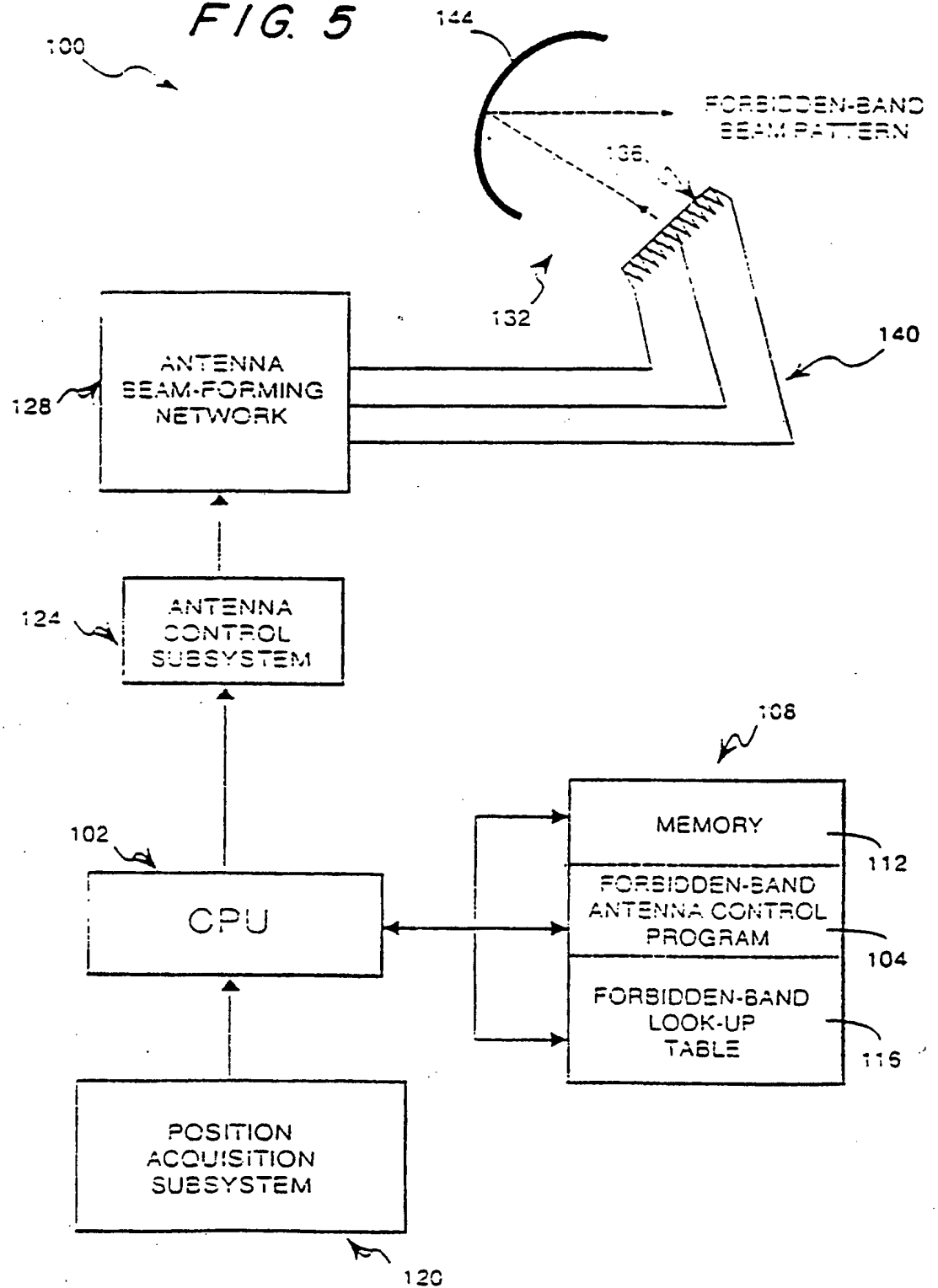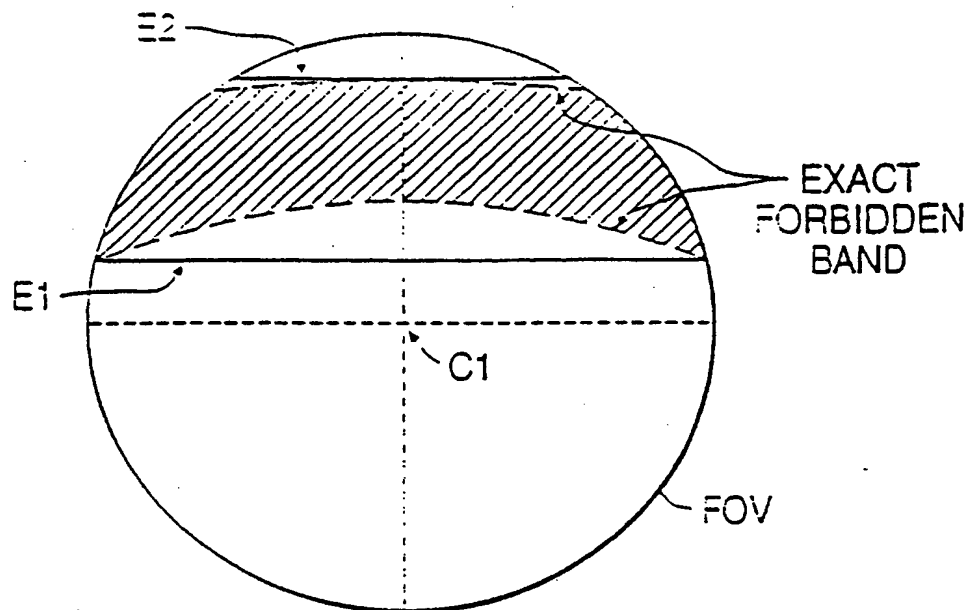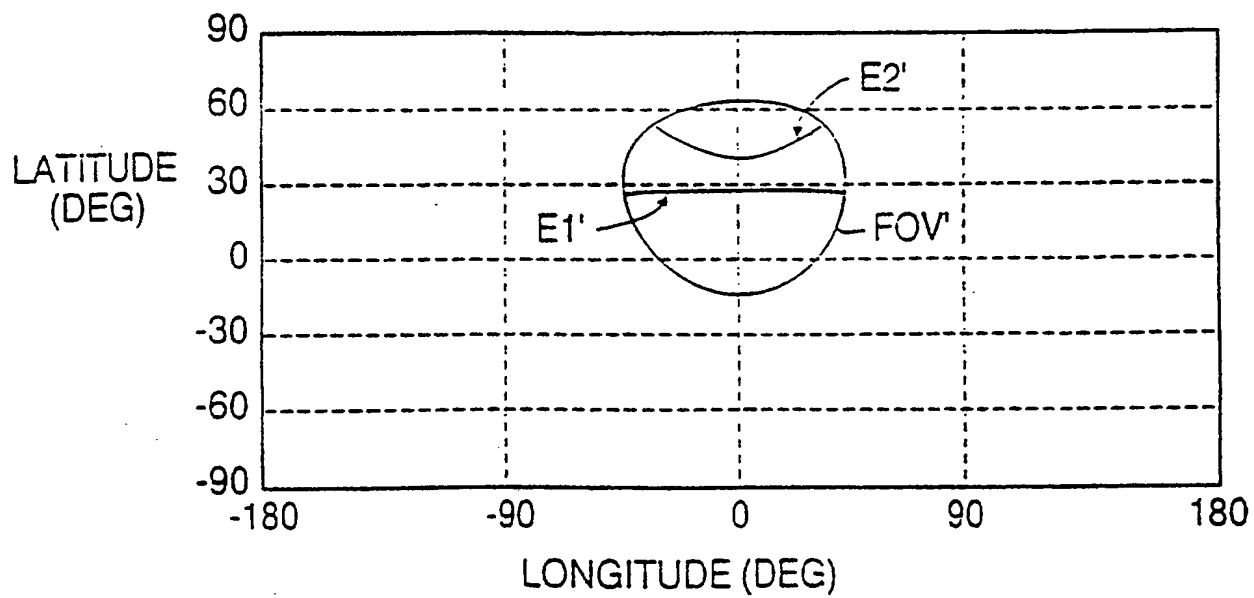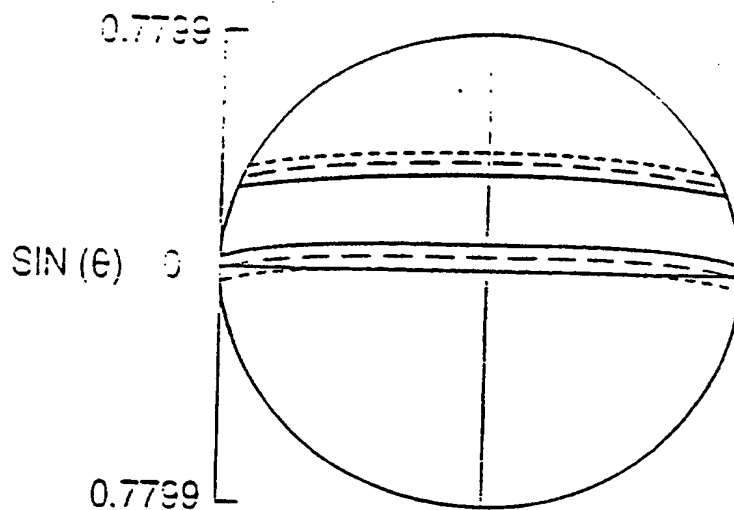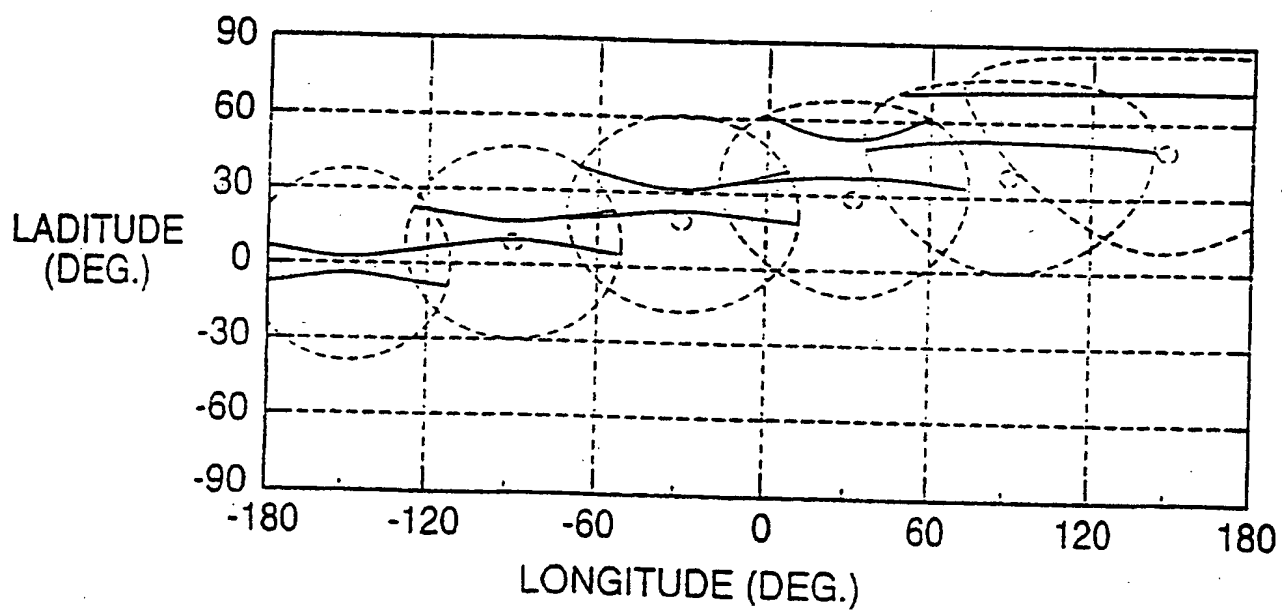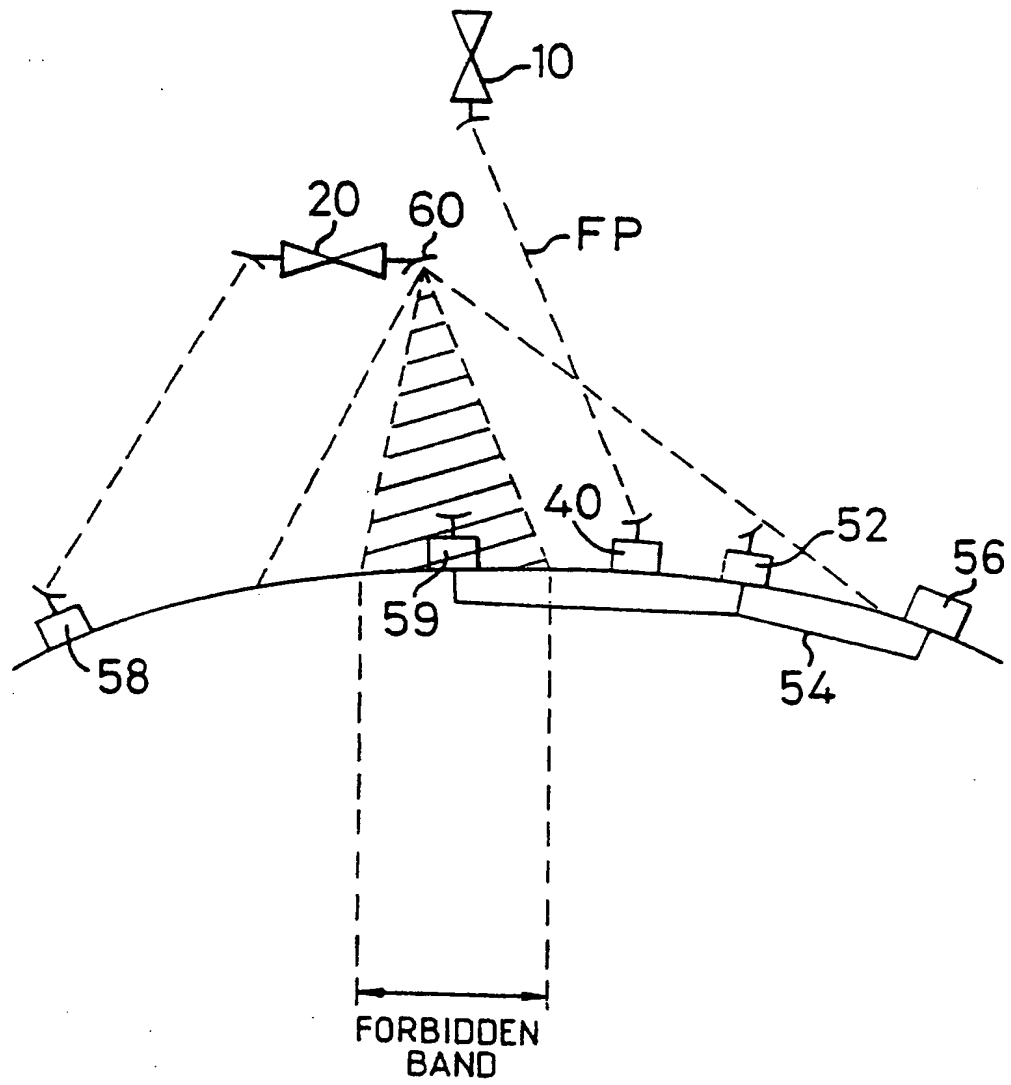
FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 5

FIG. 6

FIG. 7a

FIG. 8a

FIG. 7b

FIG. 8b

FIG.9

FORBIDDEN
BAND

FIG. 10
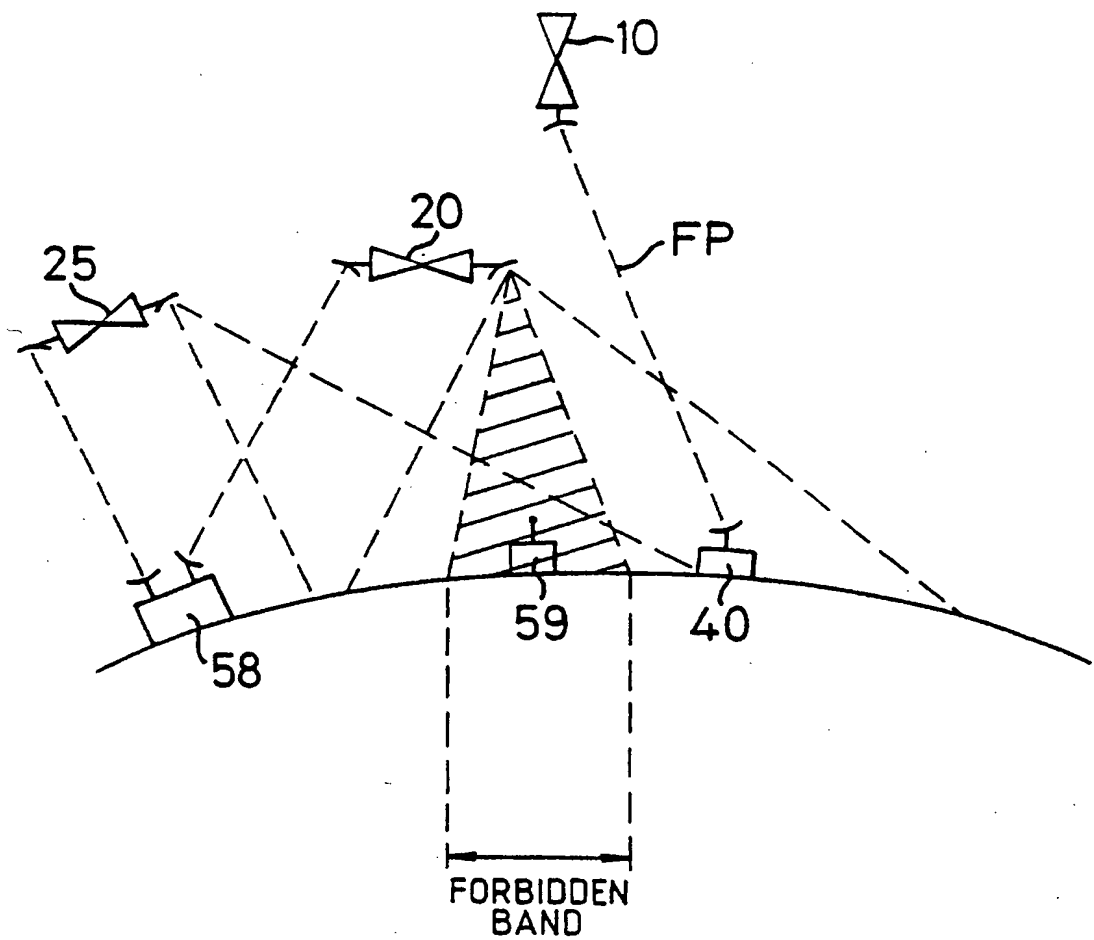
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   H04B7/185

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6   H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	1994 IEEE GLOBECOM, vol.3, 1994, SAN FRANCISCO, US; pages 1748 - 1752, XP488824 A.JAMALIPOUR ET AL. 'Signal-to-Interference Ratio of CDMA in Low Earth-Orbital Satellite Communication Systems with Nonuniform Traffic Distribution' see page 1748, right column, line 20 - page 1749, left column, line 11; figure 1 --- -/--	1-31

| X | Further documents are listed in the continuation of box C. | | X | Patent family members are listed in annex. |

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2

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	SMPTE JOURNAL, vol.98, no.12, December 1989, WHITE PLAINS, NY, US; pages 890 - 895, XP96559 G.HRYCENKO ET AL. 'Adjacent Satellite and Ground Station Interference.' see page 890, left column, line 1 - right column, line 24; figure 1 see page 892, middle column, line 21 - page 893, left column, line 27 ---	1-31
A	AVIONICS PANEL SYMPOSIUM CONF.PROC., no.488, 1990, OTTOBRUNN,DE; pages 31-1 - 31-4, XP386291 D.H.SESENSIEB ET AL. 'Performance Tradeoff of MILSATCOM Adaptive Multibeam Antennas.' see abstract see page 31-2, left column, line 10 - page 31-3, right column, line 6 ---	1-31
A	EP,A,0 587 249 (FRANCE TELECOM) 16 March 1994 see claims; figures ---	1-31
A	EP,A,0 549 220 (MOTOROLA) 30 June 1993 see column 1, line 55 - column 3, line 1; figures -----	1-31

2

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